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FLOW NOISE AND DRAG MEASUREMENTS OF VEHICLE WITH COMPLIANT COATING

by

C. R. Nisewanger

Underwater Ordnance Department

ABSTRACT. The forward portion of a buoyancy-propelled test vehicle was coated with "Lamiflo," a liquid-filled compliant rubber skin intended to reduce drag. Self-noise and drag measurements were compared with those of the bare vehicle.

The coating increased the drag slightly and shifted the transition forward, possibly because of a surface irregularity. Self-noise in the 31.4-kc band was decreased with a filling liquid having a viscosity of 2,000 centipoise but was not decreased with water filling. Turbulent boundary-layer pressure fluctuation levels (measured under the skin) were generally lower than those of the bare body, and the lower frequencies were attenuated more with the high-viscosity liquid than with water.

U. S. NAVAL ORDNANCE TEST STATION

China Lake, California

July 1964

U. S. NAVAL ORDNANCE TEST STATION

AN ACTIVITY OF THE BUREAU OF NAVAL WEAPONS

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Technical Director

FOREWORD

An investigation was undertaken to determine the effectiveness of "Lamiflo" compliant coating as a means of reducing the flow-noise component of torpedo self-noise. A significant noise reduction was attained but drag was slightly increased.

The test program was conducted during May and June 1962 as part of Project SWISH, a continuing investigation of flow noise, under Bureau of Naval Weapons Task Assignment RUTO-3E-000/216-1/F008-03-001.

The considered opinions of the Propulsion Division are incorporated in this report.

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INTRODUCTION

The coating called "Lamiflo" is a fluid-filled rubber skin intended to imitate the skin of the porpoise, which presumably is capable of maintaining laminar flow by damping the boundary-layer waves. The coating is an invention of Dr. Max O. Kramer and the initial work is reported in Ref. 1.

It was expected that if the skin reduces drag, it might also reduce flow noise. To determine whether or not such is the case, the Naval Ordnance Test Station (NOTS) conducted a series of tests at Lake Pend Oreille, Idaho, using a buoyancy-propelled test vehicle.

The Lamiflo tests had four objectives:

1. To measure flow noise sensed by a nose-mounted narrow-beam homing transducer in the 30-kc region
2. To measure the pressure fluctuations in the boundary layer at various locations along the vehicle shell in both the laminar and the turbulent regions
3. To measure effect of Lamiflo coating on drag
4. To detect any shift in transition due to Lamiflo

All of these measurements were to be compared with corresponding flow-noise measurements on a bare body that had been obtained in a previous test series. For drag determination, however, an identical bare body was tested along with the Lamiflo-coated body.

APPARATUS

THE VEHICLE

The buoyancy-propelled test vehicle is shown in Fig. 1. The Lamiflo-coated vehicle has a mass of 100.0 kg without ballast, and displaces 294.2 kg of water. For increased buoyancy, an extra section can be added. The mass of this longer body is 109.1 kg and it displaces 348.8 kg. The mass of the bare control body is 97.6 kg and it displaces 289.3 kg; it did not have the extra section. The over-all length of the body without the extra section is 314.6 cm; the over-all length of the coated body with the extra section is 362.8 cm. The diameter of both vehicles is 38.1 cm.

The Lamiflo coating (Fig. 2) was manufactured and applied by the U.S. Rubber Co. (Ref. 2). The over-all thickness is 4.57 mm, consisting of a 0.64-mm layer of high-modulus rubber under a 1.9-mm

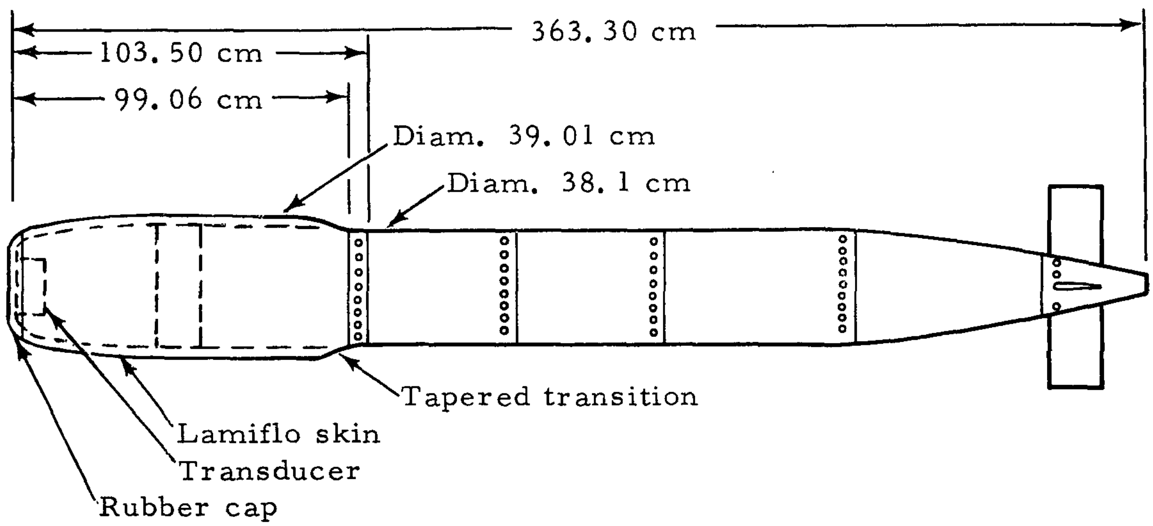

FIG. 1. Test Vehicle Assembly.

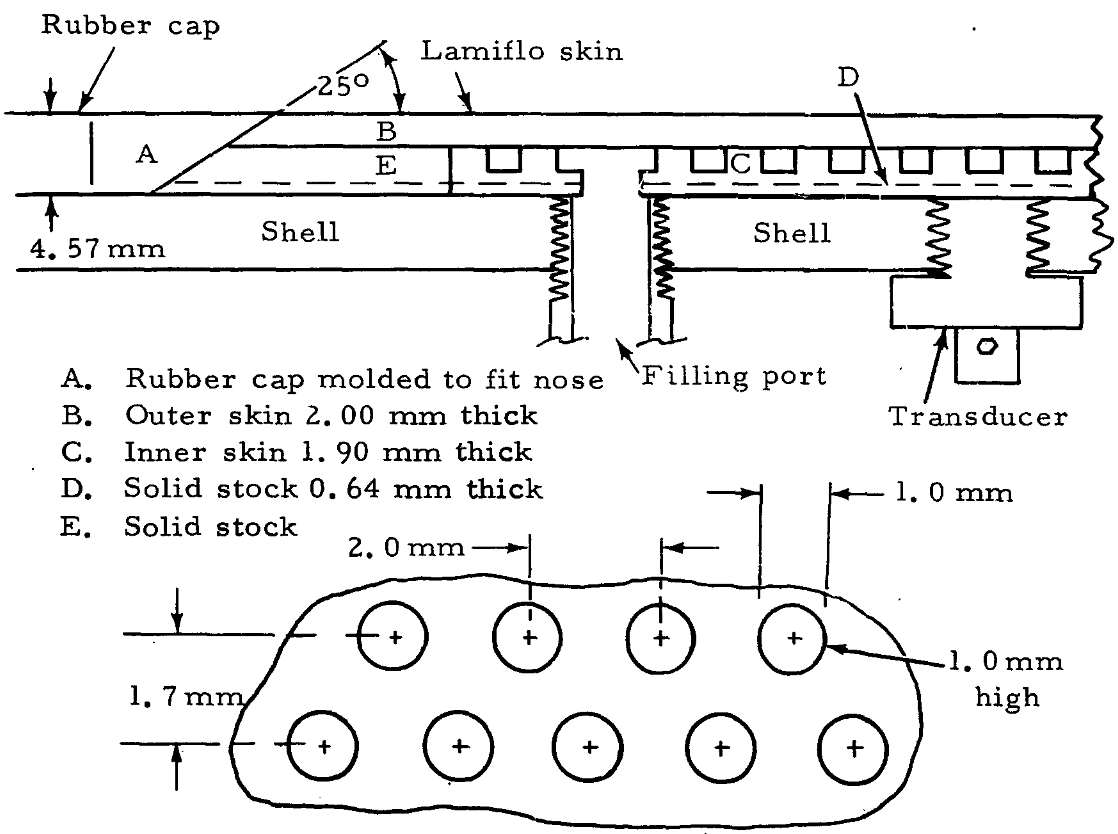

FIG. 2. Skin Design and Assembly on Shell.

layer of soft stock in which the stubs are molded; on top of this is a layer of rubber skin 2.0 mm thick. The stubs are 1.0 mm in diameter, 1.0 mm high; the centers are 2.0 mm apart and they are placed in a staggered pattern. A solid-rubber nose cap 4.57 mm thick covered the nose back to about 5 cm, and the Lamiflo coating was joined to the cap and extended 99.0 cm back from the nose. There the coating was terminated in a 3-degree taper made of surfacing putty, which faired the surface back to the original bare-body diameter.

The void in the coating is filled with liquid. To determine the effect of viscosity, both water and a high-viscosity liquid were used as filling material. The latter was a water solution of polyethylene oxide (known by the trade name "Polyox") having a viscosity of 2,000 centipoise at 4° C, the deep lake-water temperature.

INSTRUMENTATION

Two interchangeable recorder packages were used. One was designed to record the narrow-band noise pressure level as heard by a homing transducer in the nose of the vehicle and the other to record the wide-band noise pressure signal from several small transducers at various stations along the body surface. The narrow-band-level recorder, employed in several previous SWISH test programs and described in detail in Ref. 3, consists of a magnetostrictive transducer (known as type DT44) mounted flush in the nose of the vehicle and a recording package mounted in the tail. The transducer's beam pattern is shown in Fig. 3. Its on-axis sensitivity at 31.4 kc is -87 dbv/microbar. Recalibration showed that the rubber nose cap covering the transducer does not appreciably affect its performance characteristics.

The recorder package contains a log amplifier, rectifier, oscillograph, power supply, batteries, accelerometer, pitch and yaw pendulums, clock, 60-cps time-signal generator, and programmer. The programmer is started by a pressure switch that controls the recorder and the release mechanism. The accelerometer trace precisely marks the times of release and of water exit so that the run time can be determined within less than 0.01 second.

The root-mean-square noise pressure appearing at the transducer in a 2.14-kc band centered at 31.4 kc was recorded. The sensitivity of the system is such that a spectrum level as low as -81 dbs re 1 microbar can be detected. A calibration signal was recorded before or after each run with a 31.4-kc fixed oscillator in connection with a standard voltmeter and precision attenuator substituted for the transducer. Twenty levels in 2-db steps are recorded to give a complete scale throughout the 40-db dynamic range of the system.

The other recorder package, consisting of a 14-channel wide-band magnetic-tape recorder system, is used to register the dynamic pressure fluctuations in the boundary layer and the shell vibration at selected stations along the body wall. The tape recorder contains a

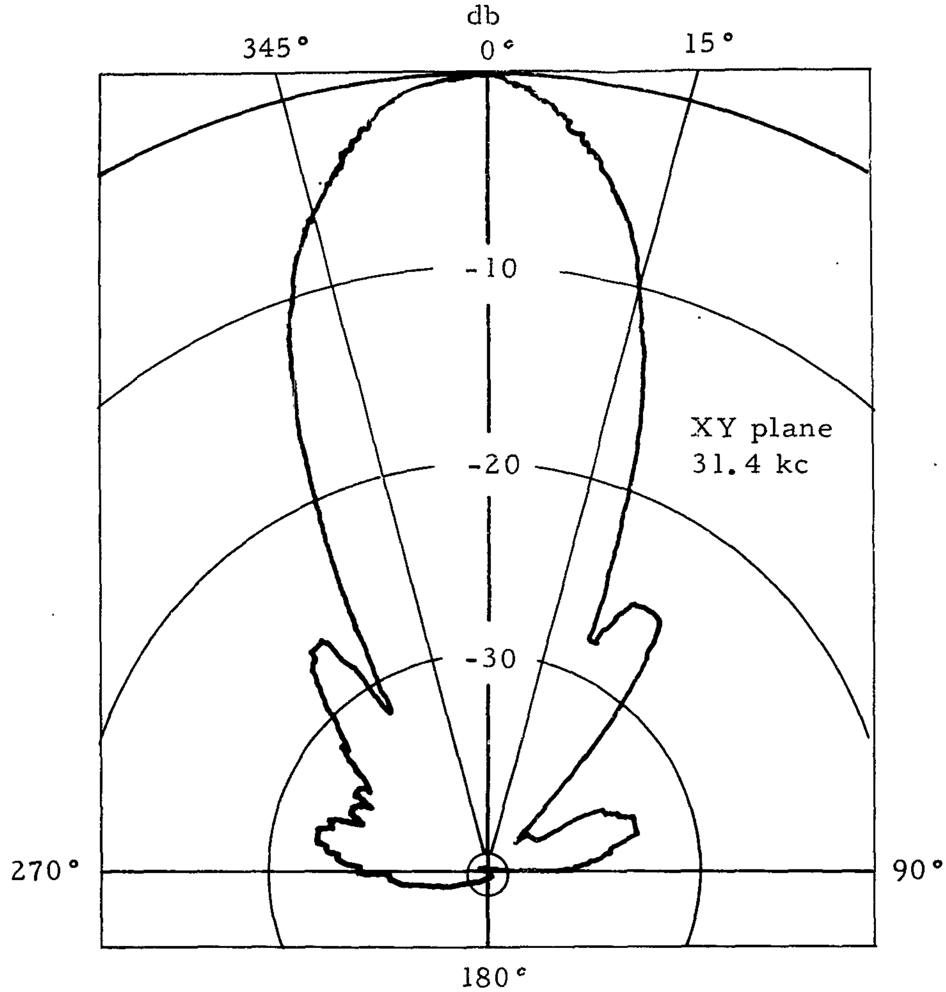

FIG. 3. Directivity Pattern of DT44C Transducer in Flat Head.

power supply, batteries, and a clock-controlled programmer that is automatically started by a pressure switch. The programmer turns on the amplifiers, starts the tape transport, and actuates the release mechanism.

For these tests, 3.1-mm-diameter barium titanate pressure transducers were placed flush with the original body surface (rather than on the Lamiflo surface, to avoid surface discontinuities) at the stations indicated in Fig. 4 and 5. The pressure transducers (Fig. 6) are a NOTS development designed for wide-band measurements. A special feature is their exceptionally low acceleration sensitivity, which enables them to be used to measure dynamic pressure fluctuations at the surface of a vibrating wall.

These transducers were calibrated acoustically both with and without the Lamiflo coating. Without the coating, the sensitivity is about

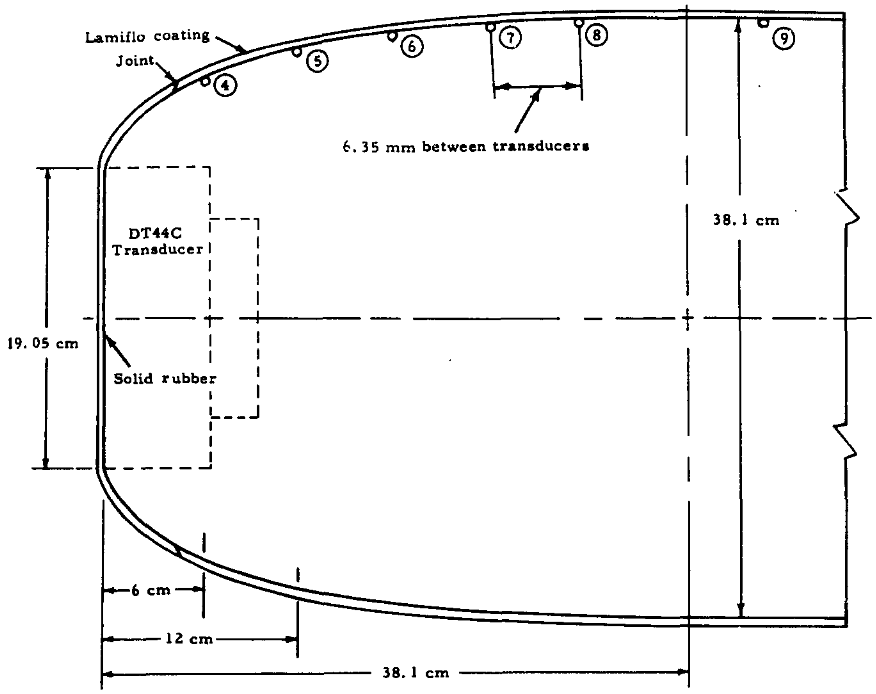

FIG. 4. Pressure Transducer Stations in the Lamiflo-Body Nose.

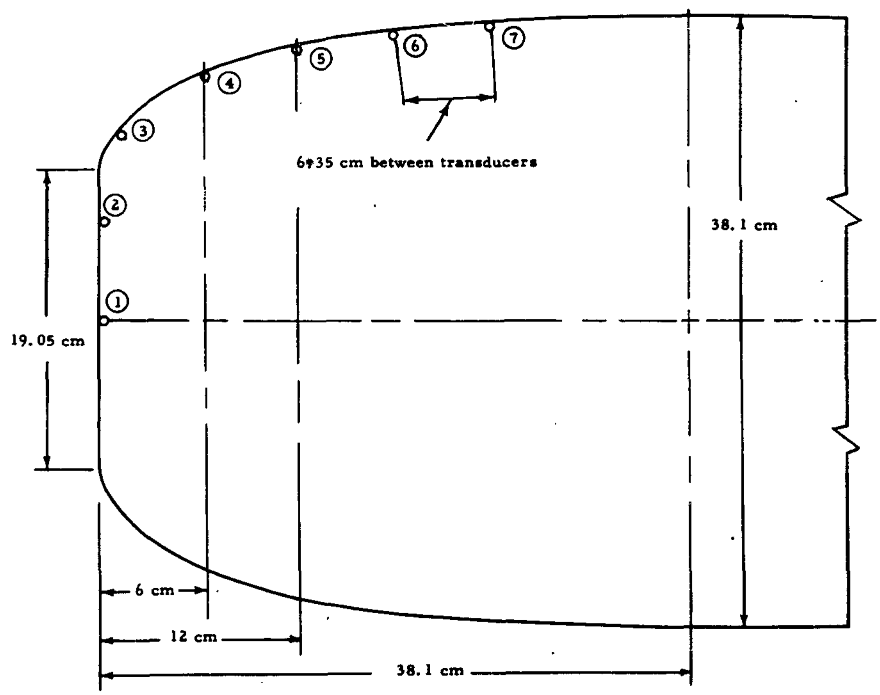

FIG. 5. Pressure Transducer Stations in Bare-Body Nose.

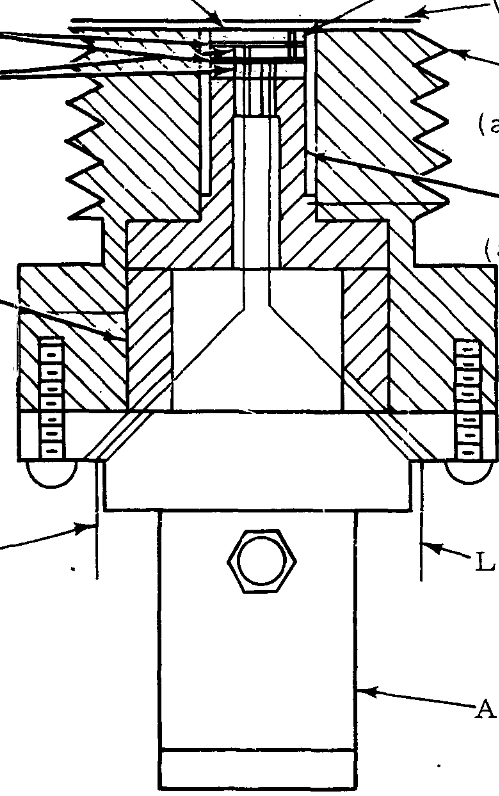

FIG. 6. Pressure Transducer Assembly.

-122 dbv/microbar and the frequency response is flat within 3 db from 100 cps to 7 kc. Although exact calibration at higher frequencies could not be obtained with the available facilities, there was no evidence of resonance peaks below 100 kc.

The coating did not affect the low-frequency response but indicated some attenuation above 2 kc that could not be measured accurately with the facilities at hand.

TEST PROCEDURE

The test setup is shown diagrammatically in Fig. 7. In operation, the vehicle is coupled to the ring and hauled down to launch depth. As the 137-meter mark is passed, the pressure switch closes, starting the programmer. In turn, the programmer switches on the amplifier to begin the warm-up, and 90 seconds later, after launch depth (usually 152 meters) has been reached, it starts the oscillograph or tape recorder and 2 seconds later actuates the release mechanism.

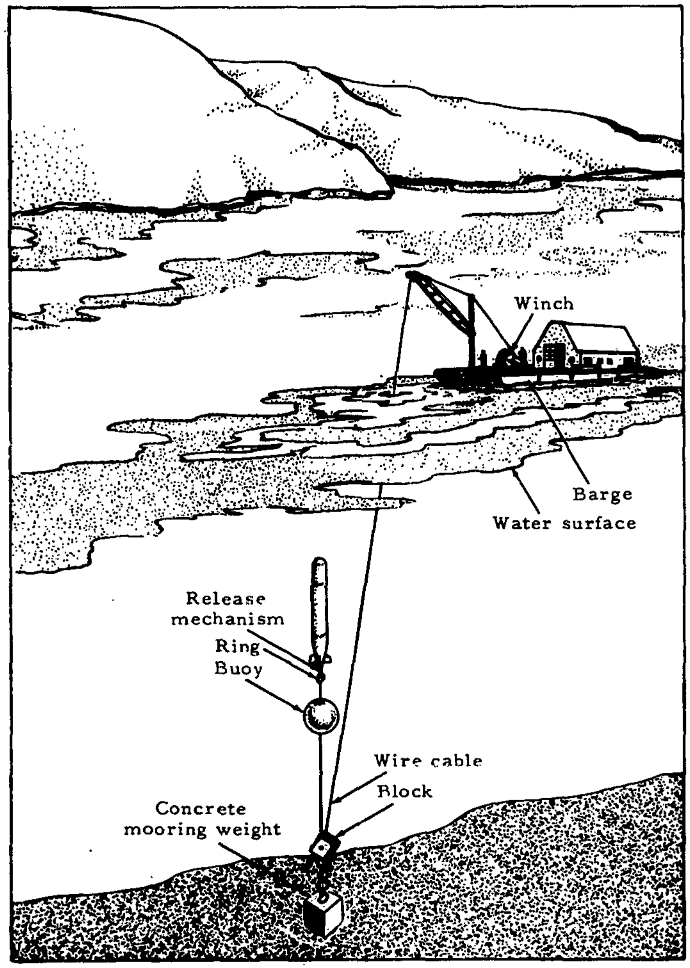

FIG. 7. Launching Facility.

The vehicle runs straight up, reaching terminal speed at a depth of about 100 meters. On emerging from the surface, it rises about 20 meters into the air (for the highest speed), falls back on its tail, and after a few bounces comes to rest floating horizontally on the surface. The programmer resets itself automatically so that several runs may be made in succession without removing the vehicle from the water.

Two ballast weights were used in addition to the normal instrument load to give three different terminal speeds; the extra section without ballast added a fourth speed. Another small ballast was used with the lighter oscillograph recorder to compensate for the difference in weight of the two recording systems.

The terminal velocity was determined from the oscillograph records as follows. The accelerometer trace marks the release time and the water-exit time. For each test configuration, the vehicle was released

from two different depths: 152 meters (the usual test depth), and 106 meters (deep enough to permit terminal velocity to be reached). The terminal velocity was obtained by dividing the difference in depth by the difference in the time of the two runs. The drag at terminal velocity is, of course, equal to the net buoyancy.

The spectral distribution of the boundary-layer pressure fluctuations was obtained by analysis of 2-second tape loops cut from the steady midportion of the runs, 50 to 90 meters deep, where speed is constant and there is no extraneous noise due to surface proximity effects. A general radio sound and vibration analyzer and graphic level recorder with a filter bandwidth of 8% of the center frequency was used for the analysis.

The transition zone was established from the tape data by comparing the pressure signals of the stations located as shown in Fig. 4. Transition, as shown in earlier tests of the bare body, is indicated by a large increase in pressure signal from all stations aft of the point of transition as compared to those ahead. This occurred between stations 4 and 5 (6 and 12 cm aft of the nose) at all speeds tested (Fig. 5). Since it was expected that transition would occur at least this far aft on the Lamiflo-coated body, the transducers at stations 1, 2, and 3 were omitted to permit the installation of the large nose transducer, DT44C, used for the 31.4-kc narrow-band-noise measurements.

External noise measurements were conducted by the David Taylor Model Basin with a wide-band tape-recorder system and a hydrophone placed about 80 meters deep and 40 meters from the test vehicle's path.

RESULTS AND DISCUSSION

The terminal drag versus terminal velocity for each vehicle configuration with ballast is shown in Fig. 8. The drag of the coated body was more than that of the bare body by about 6% for the water filling, and about 11% for the Polyox filling, which is considerably more than would result from the slightly increased dimensions of the coated body.

Figure 9 shows skin-friction drag coefficients computed from the total drag (equal to the net buoyancy at terminal velocity), which consists of the skin-friction drag, pressure drag, and fin drag. The flow over the entire body is assumed to be turbulent since the laminar flow region is less than 2% of the skin area. The pressure drag was estimated at 10% of the skin drag and the fin drag was obtained from the Schoenherr equations for flat-plate skin-friction drag. Interference drag was neglected.

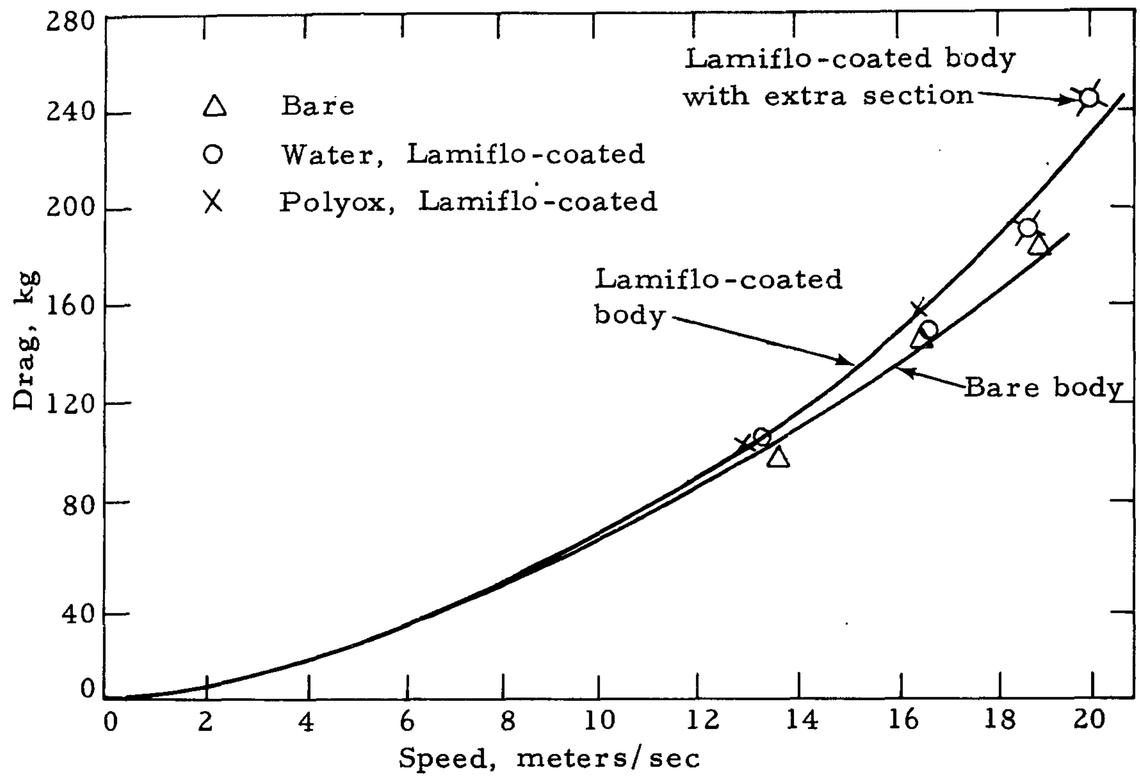

FIG. 8. Drag Versus Speed of Lamiflo-Coated and Bare Body.

The resulting equation for the skin-friction drag coefficient is

$$C_F = \frac{1}{1.1A}\left(\frac{B}{qv^2} - C_f A_f\right)$$

where A is the body skin area, B the net buoyancy, C_f the fin drag coefficient, and A_f the fin area.

Because of the assumptions, the calculation is not exact, but it yields coefficients suitable for comparing test results.

Figures 10 through 13 present the spectrum levels for the boundary-layer pressure fluctuations at stations 4, 5, 6, 7, 8, and 9 (Fig. 4). Shown in Fig. 14 are the 19.7 m/sec spectrum levels averaged for all stations. For the bare body, stations in the laminar zone are averaged separately from those in the turbulent zone.

Comparison of the curves in Fig. 14 shows that the levels obtained for the coated body lie between the two curves for the bare body at low frequencies. At higher frequencies, about 1.5 kc and above, the curves for the coated body fall more steeply than those of the bare body, due,

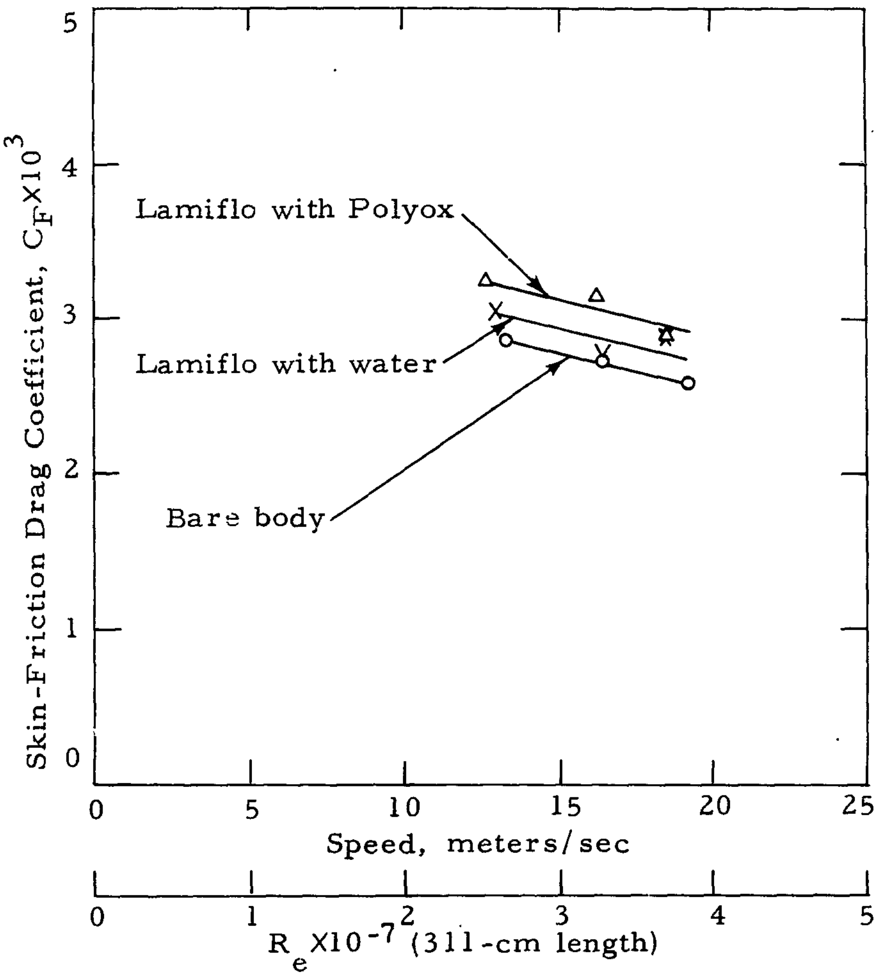

FIG. 9. Skin-Friction Drag Coefficient Versus Speed.

in part at least, to attenuation in the coating (since the transducers are under the coating).

The hydrodynamic pressure fluctuations in the turbulent boundary layer, unlike the acoustic calibrating signal, are correlated only over small areas so that the integrated output decreases as the transducer face area increases (Ref. 4 and 5). It would be expected that an integrating effect would also occur in the Lamiflo coating because lateral pressure transmission in the liquid filling would also tend to decrease the transducer response. The effective area of integration could be equated to the bare transducer-face area, which would produce the same attenuation.

The dotted curve in Fig. 14 takes into account the approximate acoustic attenuation of the coating and yields the reduced bare-body turbulent level that would have been observed as the result of this

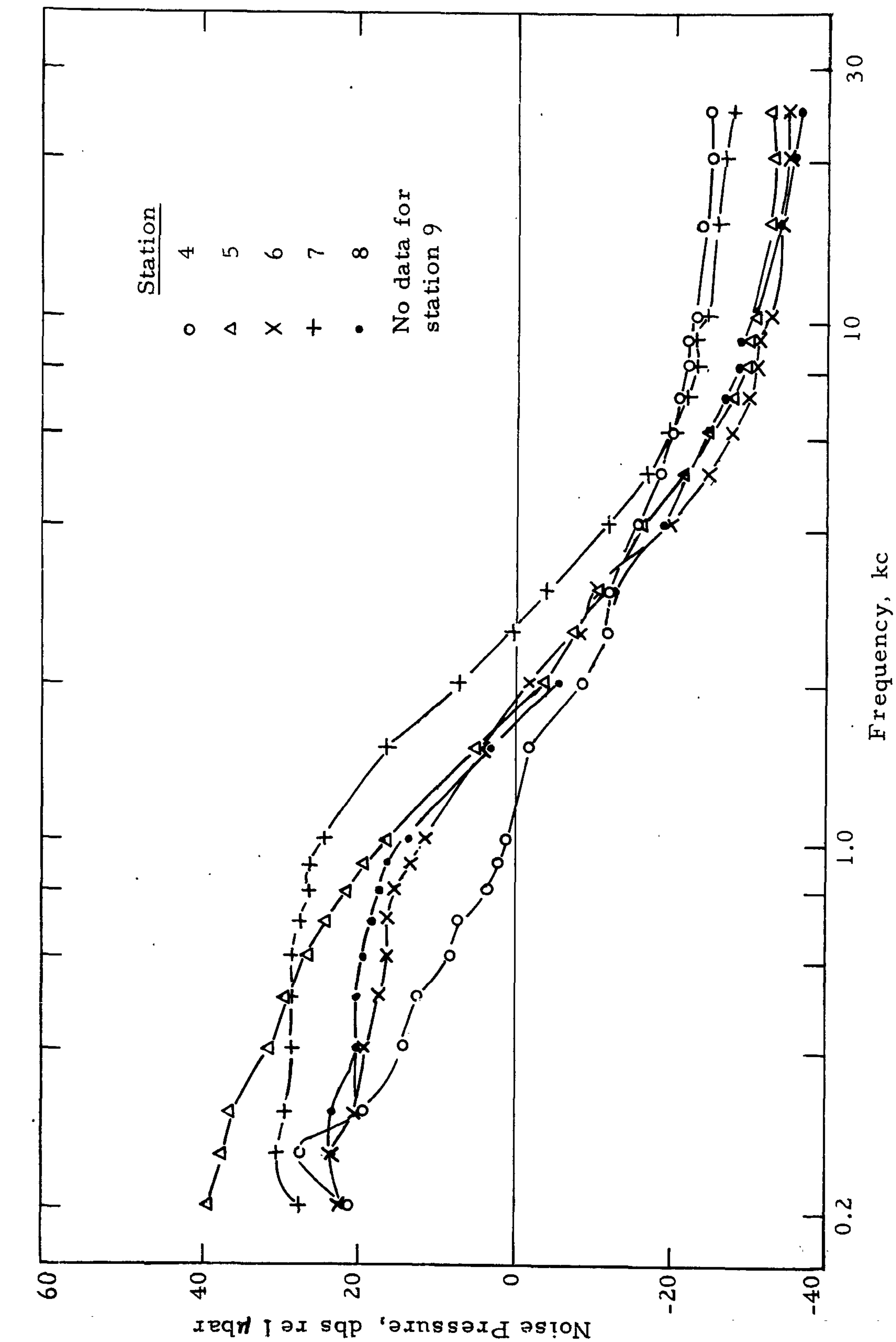

FIG. 10. Noise-Pressure Spectrum, Lamiflo With Polyox, 12.6 meters/sec.

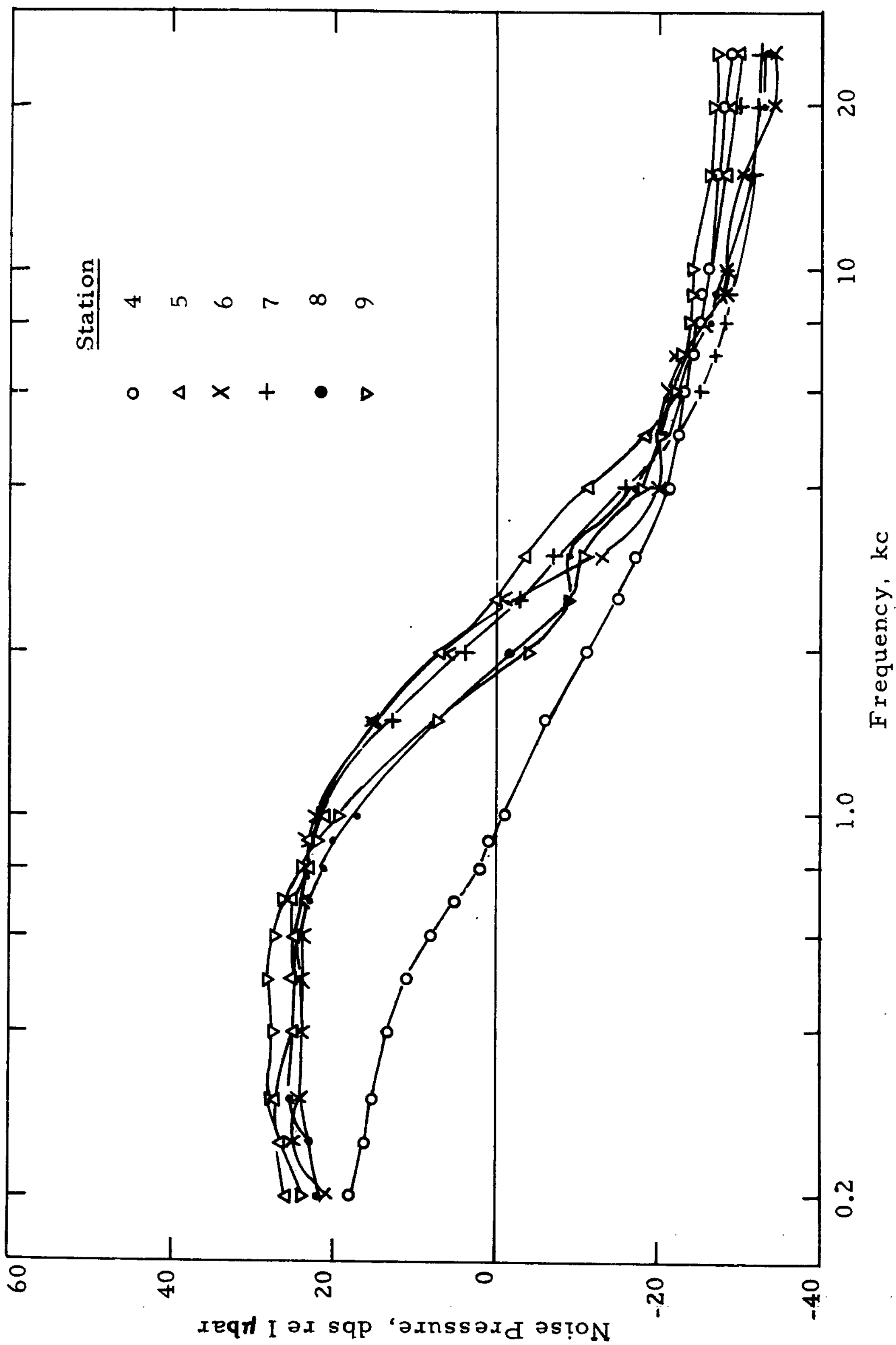

FIG. 11. Noise-Pressure Spectrum, Lamiflo With Water, 12.6 meters/sec.

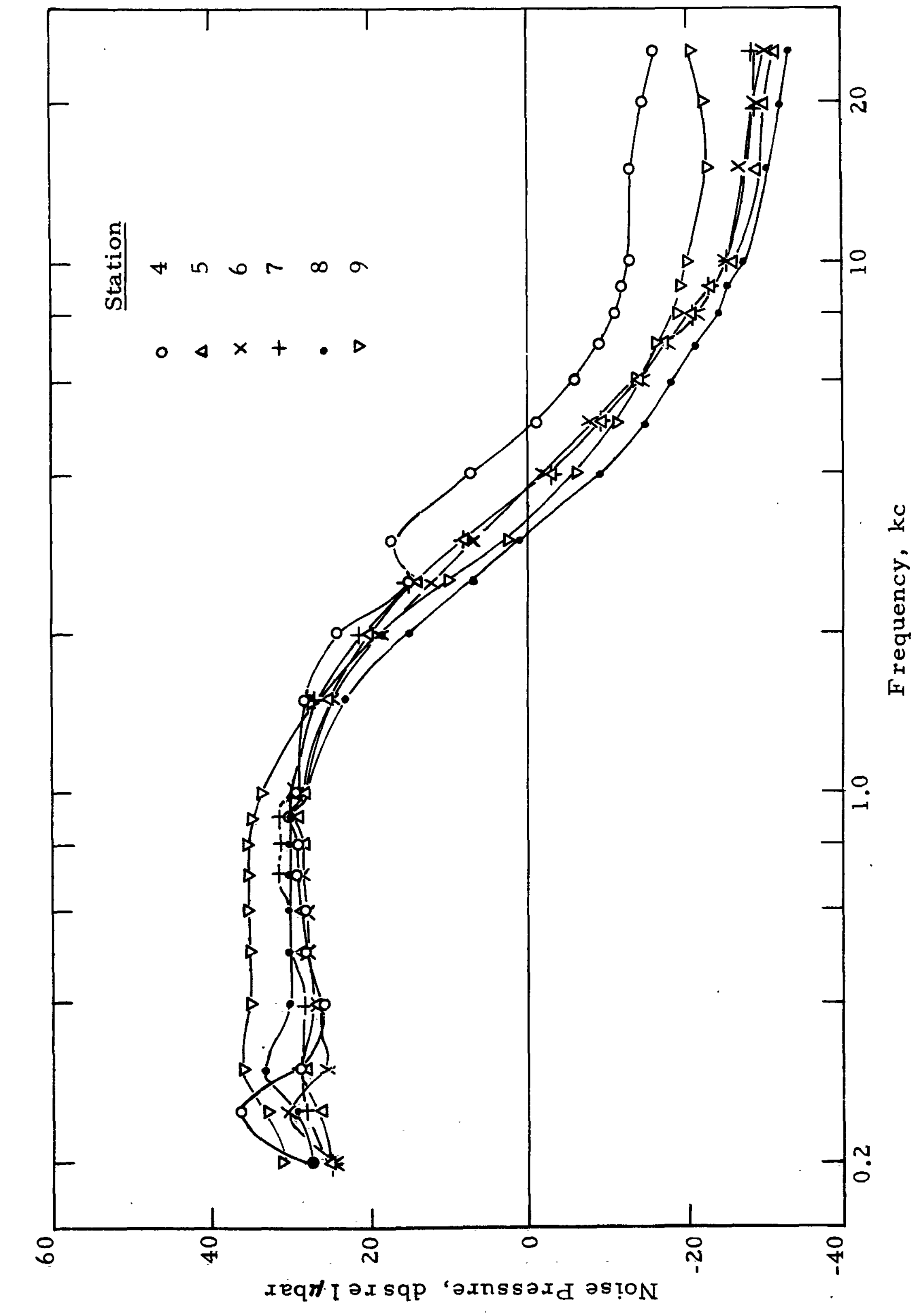

FIG. 12. Noise-Pressure Spectrum, Lamiflo With Polyox, 19.7 meters/sec.

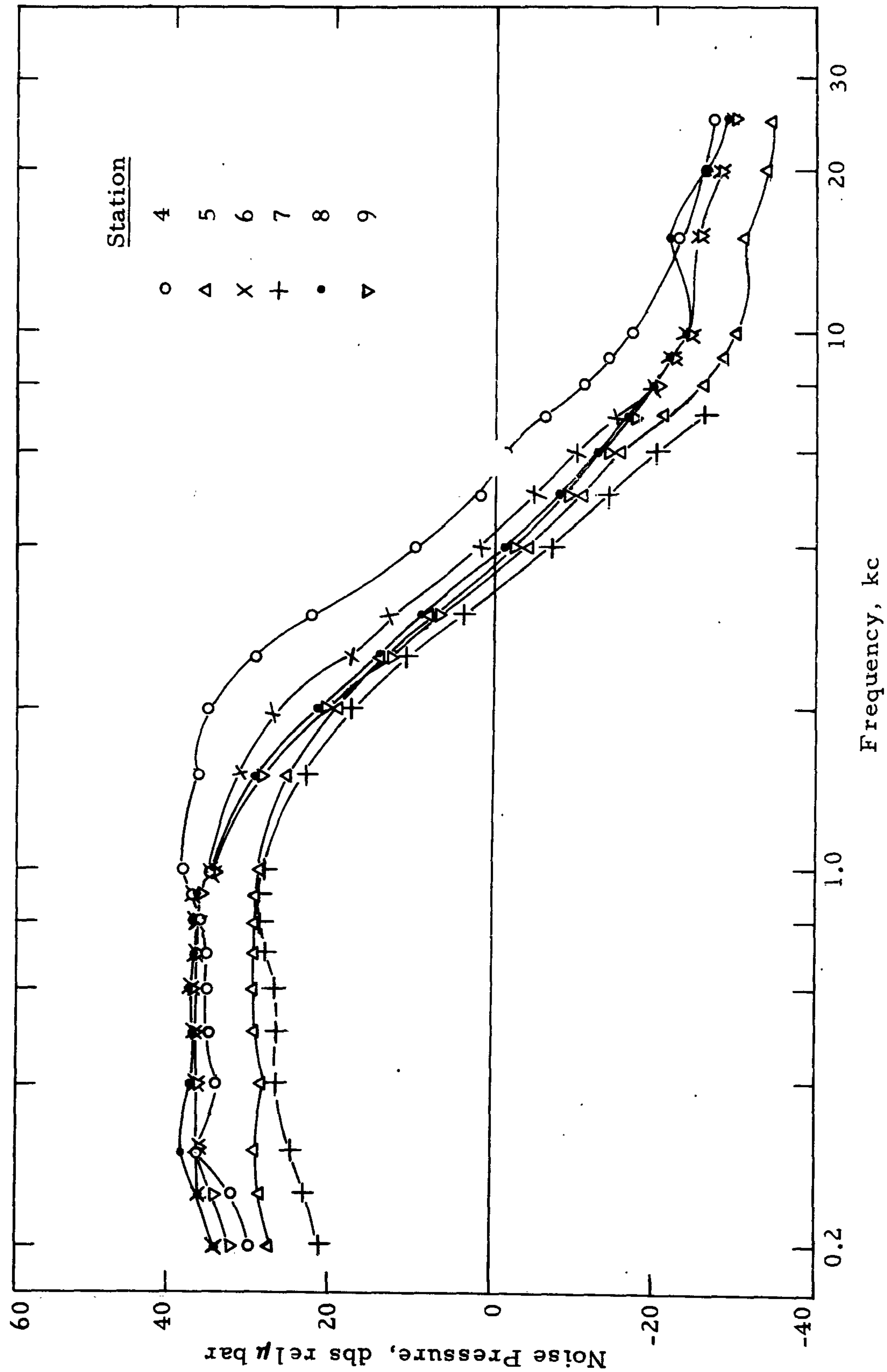

FIG. 13. Noise-Pressure Spectrum, Lamiflo With Water, 19.7 meters/sec.

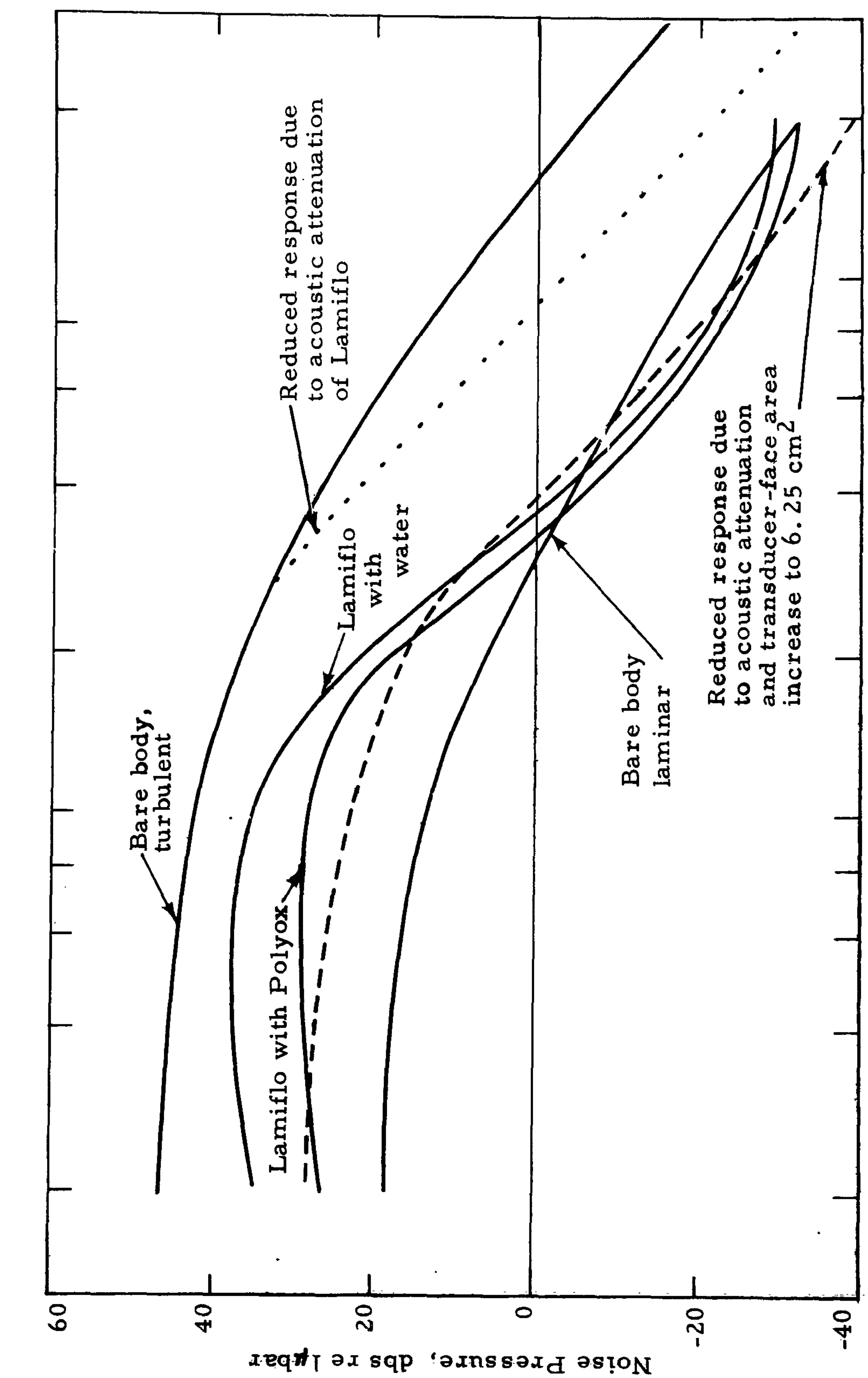

FIG. 14. Bare Body Versus Coated Body, Mean of All Stations, 19.7 meters/sec.

attenuation only. The dashed curve shows the further reduction that would have resulted if the transducer face had been increased to a 2.5-cm square (Ref. 5).

Because the shape of the latter curve differs considerably from those obtained with the 3.1-cm-diameter transducers under the coating, and also because a rather large effective area of integration must be assumed to achieve even an approximate fit, it seems reasonable to assume that at least part of the signal reduction is due to a real reduction in the boundary-layer turbulence. The quality of the data is not sufficient to attempt a quantitative evaluation of the reduction.

For the lowest speed (Fig. 10 and 11), the signal from station 4 is considerably lower than those from the stations farther aft, indicating that the laminar flow extended beyond station 4.

For higher speeds (Fig. 12 and 13), station 4 exhibits a level generally similar to that of stations farther aft, indicating that transition occurred farther forward with the coated than with the bare body.

This result, contrary to the expected one, might be attributed to tripping by a surface irregularity at the joint between the solid-rubber nose cap and the more compliant Lamiflo. However, because the bare-body transition is already downstream of the minimum pressure point in a region of unfavorable pressure gradient (Fig. 15 and Ref. 6), the coating could not have been expected to delay transition very much even though its surface were perfect.

The noise levels measured by the narrow-band 31.4-kc transducer in the nose are shown plotted versus speed in Fig. 16. Levels obtained at the higher speeds with water-filled Lamiflo are comparable to those obtained with the bare body, but for the two lower speeds, 15.4 meters/sec and 12.6 meters/sec, the levels were below the sensitivity of the recording system, -81 dbs. With Polyox 2,000-centipoise filling, the levels are considerably lower for the higher speeds but do not decrease as much with decreasing speed. (A measurable signal was obtained at 15.4 meters/sec.)

The external noise in the range of 800 cps to 10 kc, measured by DTMB (Ref. 7), showed nearly the same levels for the coated and uncoated bodies but showed a variation with speed, as did the internally recorded levels. The internally recorded shell vibration was essentially the same for the coated and uncoated bodies.

There seems to be no simple relationship between noise levels and drag. Drag was slightly greater for the coated body and it might well be expected that the noise should be similarly related to it.

It is possible that the increased drag of the coated body produced noise outside of the measured range, perhaps below 200 cps.

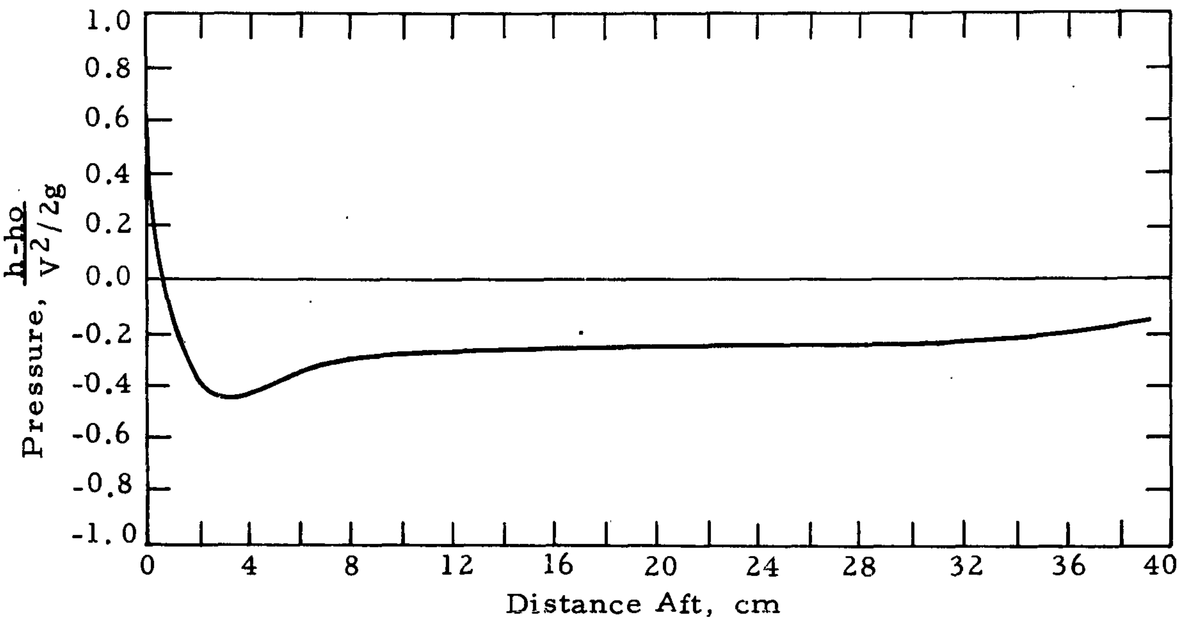

FIG. 15. Noise Pressure Versus Speed for a Lamiflo-Coated and an Uncoated Body, 31.5-kc Front Transducer.

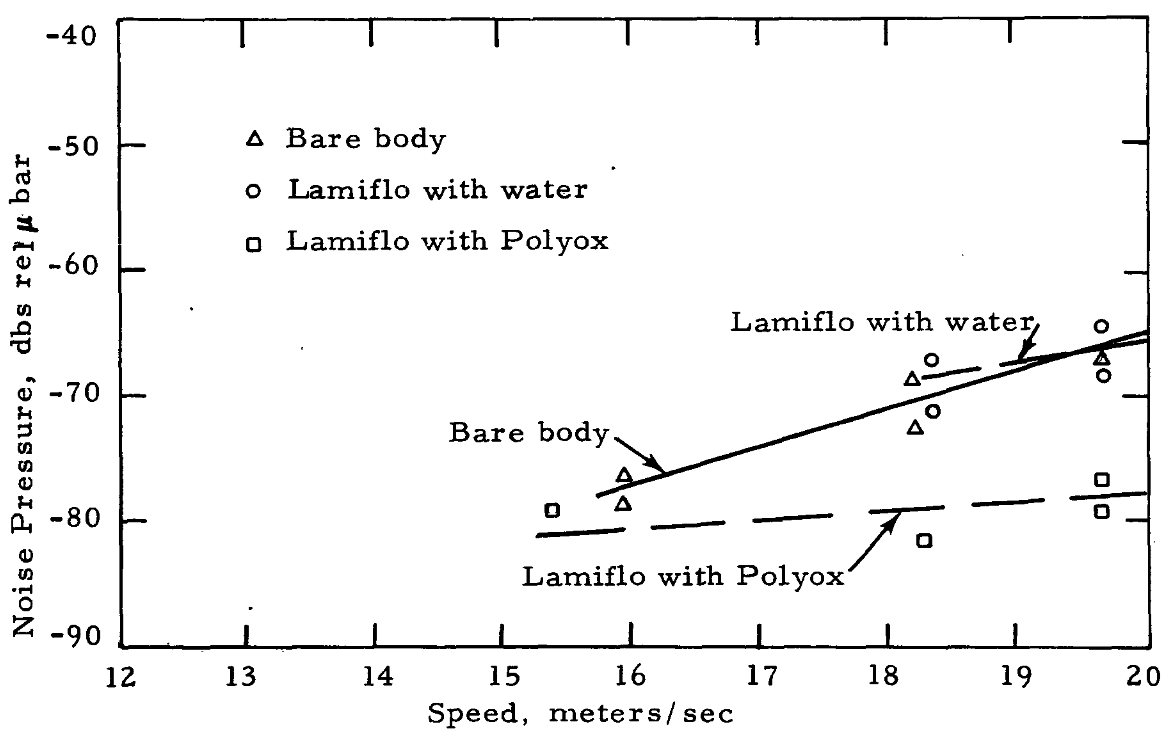

FIG. 16. Longitudinal Pressure Distribution.

Photographs made during tests of the coating in a towing basin showed static divergence (wrinkling) at speeds of 18 meters/sec and more. These wrinkles could shed large-scale vortices that would generate low-frequency noise (Ref. 8).

CONCLUSIONS

Lamiflo coating of the test vehicle increased drag. Transition was shifted forward at speeds of 15.4 meters/sec and higher. Noise in the 31.4-kc band was decreased for all speeds with Polyox 2,000-centipoise filling in the coating, but only at low speeds (15.4 meters/sec or less) with water. Spectrum levels of the turbulent boundary-layer pressure fluctuations were generally lower than those obtained with the uncoated body, and in the low frequencies, Polyox 2,000-centipoise filling produced lower levels than water filling.

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NEGATIVE NUMBERS OF ILLUSTRATIONS

Fig. 1 - 3, none; Fig. 4, LHL-P 25241-1;
Fig. 5, LHL-P 25241-2; Fig. 6 - 16, none.

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ABSTRACT CARD

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